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Between stings and smoke: prevalence of allergic disorders and exposure to combustion smokes in Northeast Italy's beekeepers

Marcella Mauro,[1] Alice Tassinari ,[1] Federico Cavallo Ronchi,[2] Marco Rizzo,[3] Francesca Larese Filon [1,3]

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[1]Unit of Occupational Medicine, Department of Medical Sciences, Surgery, and Health Sciences, University of Trieste, Via della Pietà 2/2, Trieste, Italy
[2]Unit of Otolaryngology, Department of Medical, Surgical & Health Sciences, University of Trieste, Trieste, Italy
[3]Bachelor's Degree Program in Environmental and Workplace Prevention Techniques, University of Trieste, Trieste, Italy

Correspondence to
Dr Alice Tassinari; alice.tassinari@studenti.units.it

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ABSTRACT

Objectives Beekeepers are frequently exposed to bee venom and combustion smoke, leading to risks of systemic allergic reactions and respiratory hazards. This study assesses the prevalence of systemic allergic symptoms among beekeepers in Northeastern Italy and describes current management practices. Additionally, it characterises inhalation exposures to combustion smoke during apiary maintenance.

Methods A cross-sectional survey collected data on sting exposure, allergic symptoms and smoke use practices. Combustion smoke exposure assessment was performed using Fourier transform infrared spectroscopy (Gasmet DX-4030) coupled with an ultrafine particle classifier (DiSCmini) to characterise emissions from commonly used fuels.

Results Among 553 beekeepers surveyed, 21.3% reported systemic allergic reactions after bee sting, mostly males (66.7%). Of these (n=118), only 31.4% were confirmed sensitised to *Apis mellifera* and prescribed epinephrine autoinjector; 16.1% received venom immunotherapy, while others had no specific allergological assessment. Multivariate analysis showed that allergic symptoms during apiary work and extended local reactions increased the likelihood of systemic reactions fivefold. Almost all participants used smoke during inspections, with 39.1% frequently inhaling smoke; only 0.9% used respiratory protective equipment. Environmental monitoring detected multiple volatile organic compounds—including formaldehyde exceeding at different time points the threshold limit value-short term exposure limits—and high concentrations of ultrafine particles, particularly from hay and pellet combustion.

Conclusions Systemic allergic reactions to bee venom are common but often undertreated in beekeepers. Combustion smoke is a significant respiratory hazard. Targeted interventions are needed to improve health outcomes and safety in this occupational group.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Beekeepers are known to be at high risk for systemic allergic reactions due to frequent exposure to bee venom, with prevalence varying significantly according to geographical area and case definition, and there is ongoing debate on risk factors. Moreover, smoke produced by combustion of different fuels is routinely used to calm bees.

⇒ However, the prevalence of allergic disorders and the inhalation risk associated with smoke exposure in this occupational group has been poorly characterised.

WHAT THIS STUDY ADDS

⇒ This study provides the first regional data on systemic allergic reactions among beekeepers in Northeastern Italy, identifying extensive local reactions and allergic symptoms during hive work as key risk factors. It also characterises the smoke emitted by incomplete combustion of different fuels used as a bee-calming practice, finding formaldehyde and ultrafine particle (UFP) levels of potential concern, especially considering that only 0.9% of workers used respiratory protection.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These findings highlight the need for education among beekeepers to recognise allergological symptoms early and seek specialist evaluation as needed. Allergists should especially consider prescribing bee venom immunotherapy to these outdoor workers, since it is highly effective in modifying the disease and crucial due to their high exposure risk.

⇒ Alternative methods to calm the bees that do not involve combustion smoke should be considered.

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INTRODUCTION

Beekeeping supports biodiversity conservation and agricultural production through pollination services. In Italy, 51 578 registered beekeepers manage over 1.4 million hives, with approximately 78% engaged in professional activities yielding commercial honey and hive products.[1] These practices align with the Common Agricultural Policy Strategic Plan 2023–2027 (https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_it, https://www.objectiveeuropa.com/bandi/contributi-per-lapicoltura) and receive regional support, evidenced by a 56.2% increase in beekeepers and 71.3% rise in apiaries in Friuli Venezia Giulia from 2016 to 2022 (ERSA (Regional Agency for Rural Development of Friuli

Venezia Giulia) processing on data from the National Database of the Livestock Registry—https://www.vetinfo.it/j6_statistiche/#/).

During their activities, beekeepers are exposed to risks common to all outdoor workers, such as those related to UV exposure, thermal stress and manual handling of loads, to name a few, but also to task-specific risks that deserve attention as they are less investigated. Beekeepers face occupational hazards common to outdoor workers, including UV exposure, thermal stress and manual handling, alongside profession-specific risks. Frequent bee stings cause repeated venom exposure, while incomplete combustion of fuels in portable smokers—to calm bees during maintenance—poses inhalation risks from smoke.

IgE-mediated reactivity to bee venom ranges from local swelling to extended local reactions (ELR; painful swelling ≥10 cm beyond the sting site[2]), or severe systemic reactions,[3 4] including anaphylaxis, which carries a significant mortality risk if untreated.

Hymenoptera stings rank highest among occupational anaphylaxis causes in Europe,[5] designating beekeepers as high-risk workers. Family-based operations often lack health surveillance, delaying recognition of risks or reactions.

It is therefore very important to understand the prevalence of systemic allergic symptoms in this working population and whether appropriate prophylactic/therapeutic measures are being taken, bearing in mind that in these cases epinephrine is a life-saving treatment in the event of exposure, but bee venom immunotherapy is the sole disease-modifying treatment and should therefore always be proposed if exposure is likely to recur over time.[6 7]

When it is necessary to carry out maintenance operations in apiaries, smoke usage practices are needed to calm the bees. This is usually done by generating smoke through a portable combustion chamber, called 'Smoker', in which an incomplete combustion of organic compounds is produced. Fuel choices for smokers vary by region and habit, yielding uncharacterised mixtures of volatile organic compounds (VOCs) and ultrafine particles. Emerging data link biomass smoke exposure (eg, wildfires, household cooking[8–10]) to heightened allergic sensitisation via epithelial disruption and type 2 immune pathways.[8]

This study evaluates systemic allergic symptoms prevalence, preventive measure uptake, smoke usage patterns and emissions from common fuels among Northeastern Italian beekeepers.

METHODS

Epidemiological survey

Between April and June 2022, a structured, anonymous questionnaire consisting of 40 items was distributed via the mailing lists of beekeeper associations in Northeast Italy to their members (questionnaire available upon request). The questionnaire was divided into three main sections. The first section collected personal and occupational information, including demographic data, beekeeping activities, use of personal protective equipment (PPE), years of experience and number of hives managed. The second section focused on exposure to bee venom and related reactions, asking participants about the frequency and number of bee stings, symptoms experienced, their severity and treatments received. The third section addressed exposure to inhalants commonly encountered during beekeeping, including smoke usage practices, type of fuels used, the need for phytosanitary products and the use of respiratory PPE during high-risk activities.

Smoke characterisation

During the second phase, field measurements of combustion smoke were conducted under conditions representative of typical exposures identified in the survey. The following fuels were tested: pellets, hay, cardboard, jute, plastic paper and sulphur dioxide. Each fuel was separately ignited and placed in a portable combustion chamber (smoker), with emissions discharged into the environment through a truncated cone cover. The operator then performed standard apiary maintenance activities. Environmental monitoring was conducted by positioning the sampling probe in the operator's breathing zone for a 15-min period, corresponding to the average duration of routine apiary maintenance during honey production. Real-time analysis used Fourier transform infrared spectroscopy for continuous, simultaneous detection of 20 preset molecules (Fourier Transform Infrared Spectroscopy (FTIR), Gasmet DX-4030 Gasmet Technologies Oy, Helsinki, Finland). Results were compared with the threshold limit value-short term exposure limits (TLV-STEL) where available (https://www.acgih.org/science/tlv-bei-guidelines/tlv-chemical-substances-introduction/). Additionally, the concentration of microparticles and nanoparticles, along with lung-deposited surface area (LDSA), was quantified using a miniature diffusion size classifier (DiSCmini; Testo, West Chester, Pennsylvania, USA) operating at 1 Hz time resolution and 1.0 L/min ± 0.1 L/min flow rate, measuring particles in the 0–300 nm diameter range.

Statistical analysis

Data were collected using Excel spreadsheets and analysed with STATA software (V.16 SE, Stata Corporation, College Station, Texas, USA). After conducting the normality test, continuous independent variables were analysed using either T-tests (for normally distributed data) or Wilcoxon sum-rank tests (for non-normally distributed data). Categorical independent variables were compared using χ^2 tests or Fisher's exact test (for very small samples). Statistical significance set at $p<0.05$ was established. Univariate logistic regression assessed association between outcomes and risk factors; significant variables were entered into multivariate logistic regression models.

RESULTS

Characteristics of the study population

553 beekeepers completed the questionnaire, yielding a response rate of 27.4% (553/2018). Respondents were predominantly middle-aged males (78.5% male, mean age 47.2 (SD 13.0) years), with more than 5 years of experience (69.5%) and mostly professional/semiprofessional (68.5%), as shown in table 1.

Bee sting during inspection and maintenance activities was common (99.3%, n=549), even with anti-sting PPE use (82.6%, n=457), with 81.7% (n=452) reporting up to 100 bee stings/year. Massive venom exposure (>50 stings/day), possibly leading to toxic systemic reaction, was uncommon (15.9%, n=88).

ELR occurred in 16.5% (n=91), while 21.3% (n=118) reported systemic reaction symptoms (eg, distant itching/swelling, urticaria, dizziness, dyspnoea, hoarseness, palpitations, tachycardia, weakness, loss of consciousness, abdominal pain, nausea, vomiting), or epinephrine pen prescription, mostly after less than 50 stings (84.3%). Emergency care was sought by 12.5% (n=69). Among systemic reactors, 31.4% received epinephrine autoinjector prescription and 16.1% bee venom immunotherapy.

ELR was more frequent among systemic reactors (37.3% vs 10.8%, $p<0.001$).

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Table 1 Participants' characteristics

	N (%)
Participants	553 (100)
Males	434 (78.5)
Females	119 (21.5)
Mean age (SD) years	47.2 (13.0)
Years of beekeeping practice	
<5	199 (30.5)
≥5	454 (69.5)
Hours of beekeeping/year (median, IQR)	200 (100–700)
No. of other jobs besides beekeeping	105 (19)
Number of hives owned	
<10	183 (33.1)
≥10	225 (49.7)
>100	154 (26.2)
Work for other beekeepers	53 (9.6)
Use of anti-sting PPE	
No	38 (6.9)
Yes and I don't get any sting	68 (12.3)
Yes but I still get stings	457 (82.6)
Number of stings per year	
0	4 (0.7)
<10	206 (37.3)
10–100	246 (44.5)
>100	97 (17.5)
More than 50 stings/day in apiary at least once in lifetime	88 (15.9)
ELR*	91 (16.5)
Worse early season symptoms after stings	99 (17.9)
One or more systemic symptoms after sting†	118 (21.3)
≥50 stings	14 (11.9)
<50 stings	104 (88.1)
ED access after sting	69 (12.5)
Allergic symptoms while visiting apiary	47 (8.5)
Family atopy history	171 (30.9)
Allergic diathesis	144 (26.0)
NCDs	113 (20.4)
Allergological assessment at least once in lifetime	217 (39.2)
Sensitisation	171 (30.9)
Apis mellifera (IgE)	37 (6.7%)
Mites	12 (2.2)
Pollen	37 (6.7)
Other IgE-mediated and multiple sensitisation	58 (10.5)
Other cell-mediated	9 (1.6)
Prescribed bee venom desensitisation therapy	19 (3.4)
Prescribed epinephrine auto-injector after bee sting	37 (6.7)
Prescribed epinephrine auto-injector after bee sting and desensitisation therapy	18 (8.3)
Hand dermatitis during peak season	39 (7.1)
Use of antistaminics or cortisone	144 (26)
For other allergens (for other)	72 (13.0)
For bee sting	74 (13.4)

*Skin swelling more than 10 cm.
†Systemic symptoms: one or more of the following: itching/swelling distant from sting site, urticaria, dizziness.
ED, emergency department; ELR, extensive local reaction; NCDs, non-communicable diseases; PPE, personal protective equipment.

Predisposing factors included personal allergic diathesis (26%, n=144, eg, allergic rhinitis and/or conjunctivitis, nasal polyposis, asthma or atopic dermatitis), family allergy history (30.9%, n=171) and apiary-related symptoms (8.5%, n=47, eg, nasal congestion, runny nose, coughing, sneezing or eye irritation during visiting apiary). Lifetime allergological evaluation occurred in 39.2% (n=217), with 17.1% (n=37) *A. mellifera*-sensitised (all prescribed autoinjectors; 51% (n=19) received venom immunotherapy).

Systemic reactors were younger (median 42 (IQR 35–51) vs 48 (39–57) years, p=0.002) and had higher ELR prevalence (37.3% vs 10.8%, p<0.001) and more apiary symptoms (18.6% vs 5.7%, p<0.001). Epinephrine-prescribed individuals reported fewer stings/year compared with not reactive subjects (56.8% vs 36.6%, p<0.015). Sensitisations of systemic reactors are reported in online supplemental material 2.

Multivariate logistic regression confirmed apiary allergic symptoms (OR 4.9, 95% CI 2.08 to 11.6, p<0.001) and ELR (OR 4.8, 95% CI 2.27 to 10.37, p<0.001), as risk factors for anaphylactic reaction (table 2, figure 1).

Smoker use practices and fuel types

Nearly all participants (98.5%) used smokers, with 58% (n=321) employing them for most hive work time (online supplemental material 1). Frequent smoke inhalation was reported by 39.1% (n=216), while only 0.9% (n=5) used respiratory PPE. Three main fuel categories were identified: wood/pellets/brushwood (58.3%, n=318), cardboard/plasticised cardboard (23.1%, n=126) and textile fibres (18.5%, n=101). Additionally, 62.7% used combustion-sublimated oxalic acid for *Varroa destructor control*, with 89% (n=312) wearing respiratory PPE with organic smoke filters. For winter honey super preservation, 48.8% (n=270) applied sulphur combustion smoke (sulphur dioxide (SO_2)), but only 41.5% (n=112) used appropriate PPE; 15.8% opted for freezing, and 15.3% (n=64) aerosolised *Bacillus thuringiensis* (biohazard level 1).

Smoke environmental monitoring

Combustion smokes from pellets, hay, cardboard, plasticised paper and jute were characterised. Of the 20-substance library, 16 compounds were detected in the operator's breathing zone. Figure 2 presents boxplots of emission concentrations measured by GASMET FTIR. Median values remained below TLV-STEL limits for all detected compounds; however, formaldehyde frequently exceeded at some points the threshold across most fuels—particularly coated paper—and sulphur dioxide exceeded limits during sulphur combustion.

Figure 3 shows boxplots of particle emissions measured by DISC-mini device. Hay and pellets produced median particle diameters in the nanometre range (1–100 nm) and significantly higher LDSA, a key metric reflecting alveolar surface area available for particle deposition[11,12] and increasingly used in ambient air monitoring in European urban environments.[13]

DISCUSSION

This study assessed allergic reaction prevalence among 553 Northeastern Italian beekeepers via online survey, alongside field monitoring of smoke exposure from common fuels.

Lifetime self-reported systemic reaction prevalence to bee venom was 21.3%, with 34.3% deemed clinically significant (leading to allergist evaluation and epinephrine autoinjector prescription). This falls between higher Finnish (26%)[14] and lower German (4.4%), Italian[15] (9.5%) and Slovenian[16] (9.4%) rates, though direct comparisons are limited due to varying case definition. Females (21.5% of the sample) reported nearly

Table 2 Univariate and multivariate logistic regression analyses of the prevalence of epinephrine-prescribed systemic allergic reaction to bee venom and related risk factors among the interviewed beekeepers (n=553)

	Univariate logistic regression			Multivariate logistic regression		
Item	**OR**	**95% CI**	**P value**	**OR**	**95% CI**	**P value**
Sex (female ref)	0.39	0.19 to 0.77	0.007	0.64	0.29 to 1.40	0.264
Age	0.97	0.94 to 0.99	0.032	0.98	0.95 to 1.02	0.391
Allergic symptoms while working in apiary	7.36	3.46 to 15.65	<0.001	4.90	2.08 to 11.56	<0.001
Allergic rhinoconjunctivitis	2.39	1.11 to 5.14	0.026	1.71	0.69 to 4.24	0.250
Asthma	2.96	0.94 to 9.27	0.063	1.80	0.48 to 6.80	0.384
Atopic dermatitis	2.17	0.47 to 10.03	0.320	1.73	0.33 to 9.22	0.518
Family history of atopy	2.39	1.23 to 4.63	0.010	1.13	0.50 to 2.56	0.769
Extensive local reactions (ELRs)*	6.15	3.11 to 12.19	< 0.001	4.85	2.27 to 10.36	<0.001

*The onset of symptoms generally occurs more than 6 hours after the sting, with a peak after 24–48 hours. The resolution of symptoms occurs gradually over a period of 3–10 days. The induration extends from the site of the sting and is typically more than 10 cm in diameter, sometimes involving an entire extremity.

double the systemic reactions of males (30.3% vs 16.6%), potentially reflecting true risk or gender-related reporting bias.[17]

Systemic reactors were predominantly male yet younger than non-reactors, with higher ELR prevalence and apiary symptoms; epinephrine-prescribed individuals reported fewer annual stings. These align with prior findings on age, ELR, apiary symptoms and lower sting/year exposure.[14 16 18] ELR history and apiary symptoms emerged as systemic reaction risk factors, as reported in other studies,[16 19 20] unlike working seniority and allergic diathesis.[14 21 22]

Only 16.7% of systemic reactors received venom immunotherapy, despite broader potential benefit. Venom immunotherapy demonstrates disease-modifying efficacy[7] and is recommended for recurrent-exposure scenarios like beekeeping, by several authors[23–26] and also by Italian guidelines.[6] Desensitisation merits promotion as secondary prevention, given limited occupational surveillance in this working group and 25% unawareness among reactors.

Nearly all (98.5%) used smokers, 58% for most hive time—equating to ~2.5+ daily hours for professionals (>10 hives), seasonally variable. Environmental monitoring detected VOCs, inorganic/acid smokes, aromatic hydrocarbons and substantial fine/ultrafine particles (0–300 nm) in breathing zones. Median concentrations stayed below TLV-STEL, but formaldehyde frequently exceeded thresholds (especially plasticised paper, pellets, jute), and hay/pellets yielded nanoscale particles with elevated LDSA.[11 12]

Ultrafine particles (UFPs) may facilitate deep allergen transport, enhancing sensitisation; apiary symptoms (possibly from

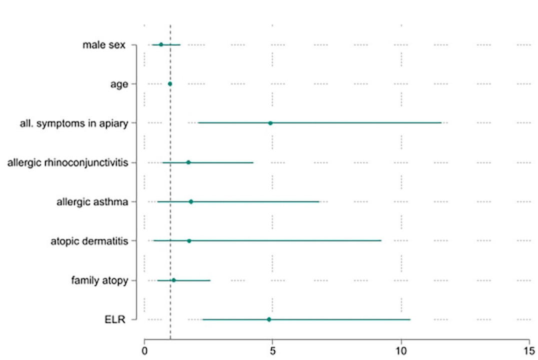

Figure 1 Forest plot of the multivariate logistic regression analysis showing adjusted ORs for personal risk factors among the interviewed beekeepers (n=553). ELR, extensive local reactions.

aerosolised bee parts sharing venom haptens)[27–29] predict systemic risk. Synergistic UFP-allergen effects could explain variable European prevalence (4.4–48.4%),[30] warranting alternative calming methods or safer fuels (avoiding hay, pellets, plasticised paper) and cross-context comparisons.

The fine and ultrafine particles detected ranged in diameter from 0 to 300 nm, with median values around 100 nm for all fuels tested. Hay and pellet smoke had significantly lower median particle diameters, higher total particle numbers and higher LDSA compared with all other fuels. This means that these particles can easily reach the lower respiratory tract, release a high amount of adsorbed substances and also translocate through the alveolar surface into the circulatory system.[11 12]

This is noteworthy given that upper respiratory allergic symptoms during inspection activities were confirmed as a risk factor for systemic reactions. Aerosolisation of bee body parts and related products debris (eg, honey and propolis) may contribute, as suggested by other authors,[27] since these materials share several haptens with bee venom.[28 29] Recent in vitro and in vivo studies demonstrated faster inflammatory responses in bronchial epithelial cells,[31] stronger allergic reactions with neutrophil lung infiltration in BALB/c mice exposed to diesel exhaust particles[32] and potent adjuvant effects of ultrafine carbon particles on allergic airway disease[33] emphasising co-exposure's role in disease onset.

A synergistic effect between bee allergens and UFPs from organic/plasticised material combustion is plausible; UFPs may adsorb and transport allergens deep into the respiratory tract, increasing contact surface area to promote early sensitisation and subsequent symptom development. Thus, evaluating smoke alternatives is crucial; if infeasible, avoiding high-impact fuels (hay, pellets, plasticised paper) could reduce respiratory pollutant emissions. Comparing smoker use habits across European contexts would be valuable, as varying allergic sensitisation/systemic reactions prevalence in beekeepers (4.4–48.4)[30] may partly reflect differences in bee allergens exposure beyond early life habits and overall environmental factors.

CONCLUSIONS

This study provides the first self-reported prevalence data on systemic reactions to bee venom in Northeastern Italian beekeepers, revealing greater female impact (despite comprising 21.5% of respondents) compared with literature—though not confirming female sex as a risk factor, as only one beekeeper study has.[34] Prior ELRs and allergic symptoms during apiary inspections were confirmed as anaphylaxis risk factors; notably,

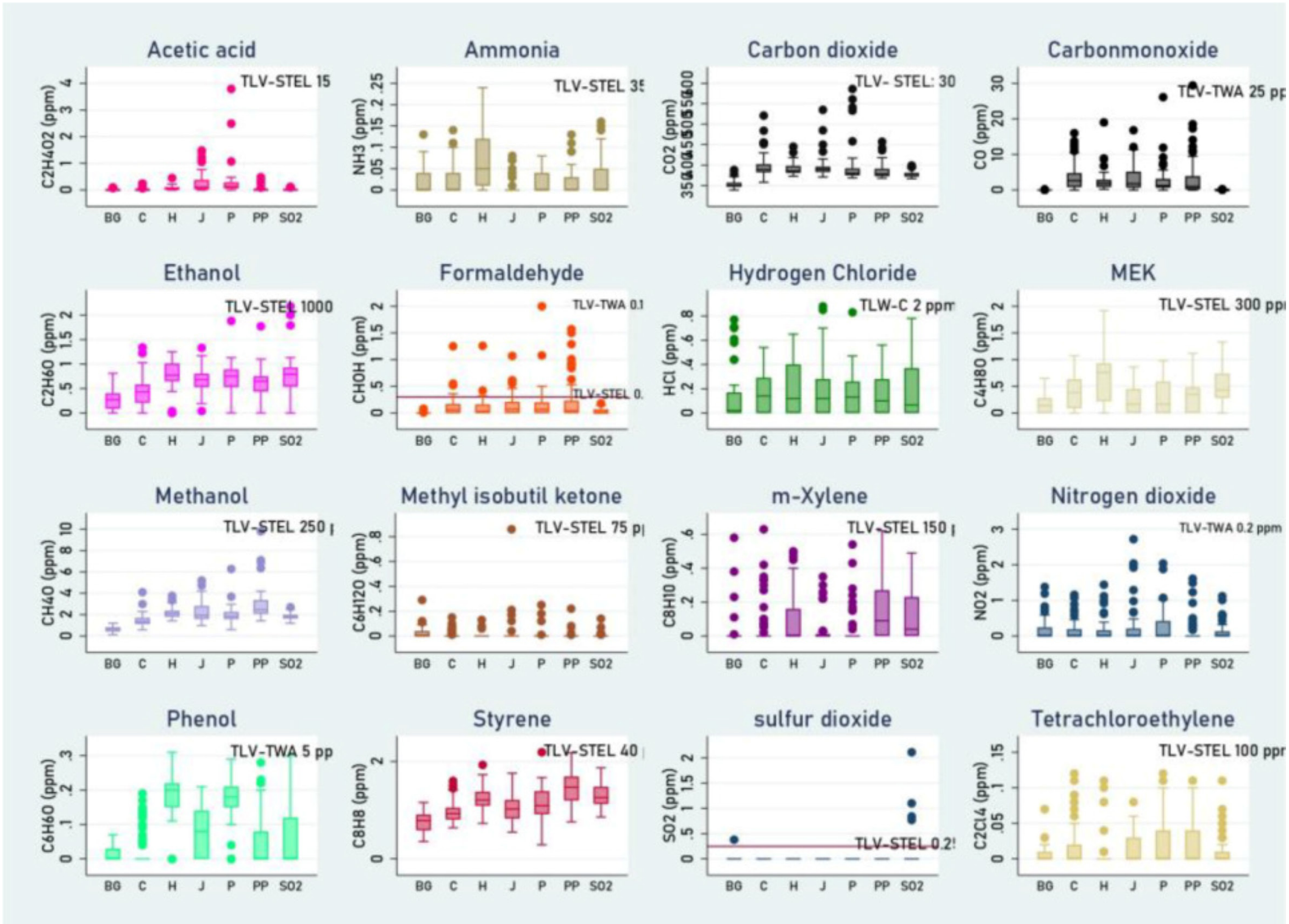

Figure 2 Boxplots showing the distribution of airborne concentrations of selected environmental contaminants measured using GASMET during the combustion of different fuels commonly used in beekeeping activities. Compounds include VOCs, inorganic gases, acidic vapours and aromatic hydrocarbons. BG, background; C, cardboard; H, hay; J, jute; MEK, methyl ethyl ketone; P, pellets; PP, plasticised paper; SO_2, sulphur dioxide; TLV-C, threshold limit value - ceiling; TLV-STEL, threshold limit value-short term exposure limits; TLV-TWA, threshold limit value - time weighted average; VOCs, volatile organic compounds.

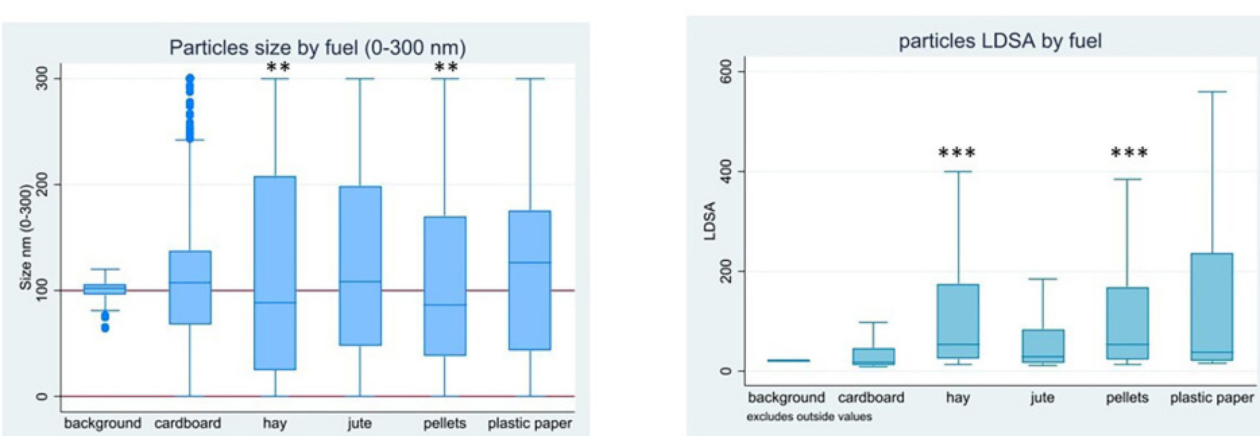

Figure 3 (a) Median size of environmental particles according to fuel type. **p<0.05 compared to all other fuels. (b) Lung-deposited surface area (LDSA) by fuel. ***p<0.001 compared to all other fuels.

a significant proportion of systemic reactors fail to recognise initial symptoms. Few venom allergic patients underwent desensitisation therapy, yet broader application merits consideration given its low side effects, disease-modifying efficacy and high re-exposure likelihood. Regional intervention studies evaluating secondary prevention strategies should target these workers/hobbyists. Environmental monitoring first characterised bee-calming smoke, detecting contaminants and non-negligible UFPs in breathing zones—a risk persisting continuously during bee activity despite outdoor setting and absent respiratory PPE in 99% of cases.

UFPs may serve as carriers for bee allergens and aerosolised bee products, enhancing deep respiratory tract delivery and accelerating sensitisation.

Certain fuels (pellets, jute) warrant avoidance due to elevated UFP emissions and plasticised paper due to high formaldehyde release. Further epidemiological studies are required in order to evaluate the current situation across Europe with particular regard to beekeepers' occupational hazard.

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Patient consent for publication Not applicable.

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ORCID iDs
Alice Tassinari https://orcid.org/0009-0006-6510-7281
Francesca Larese Filon https://orcid.org/0000-0002-7717-0417

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